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Three-dimensional patch antenna array

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Fig. 1.

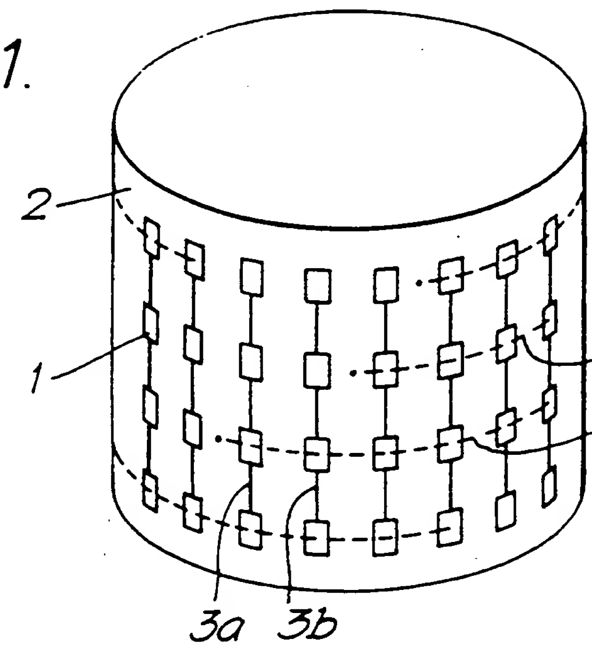


Fig. 2.

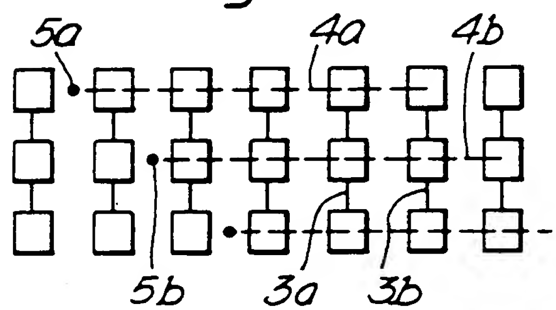


Fig. 3.

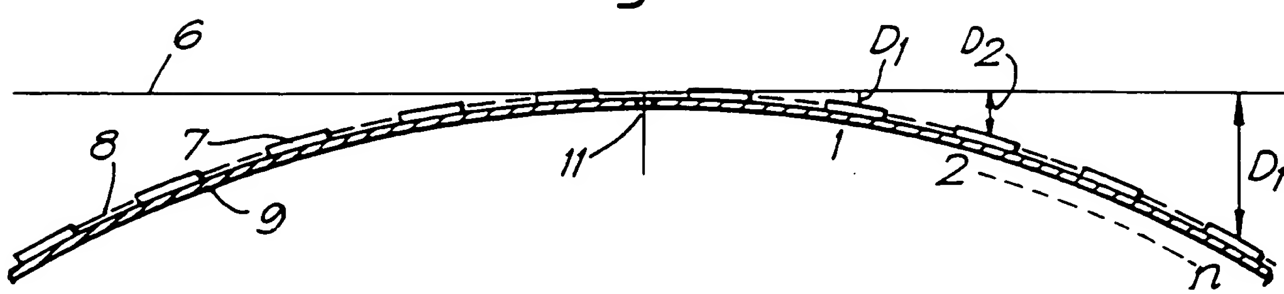


Fig. 4.

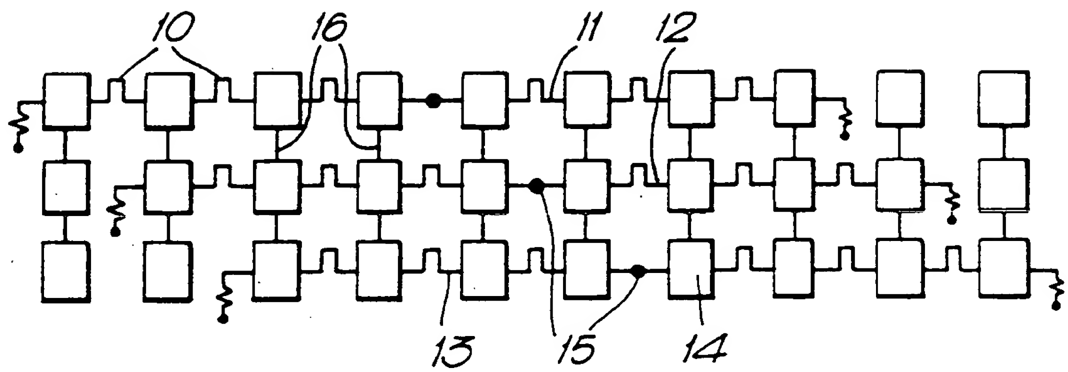
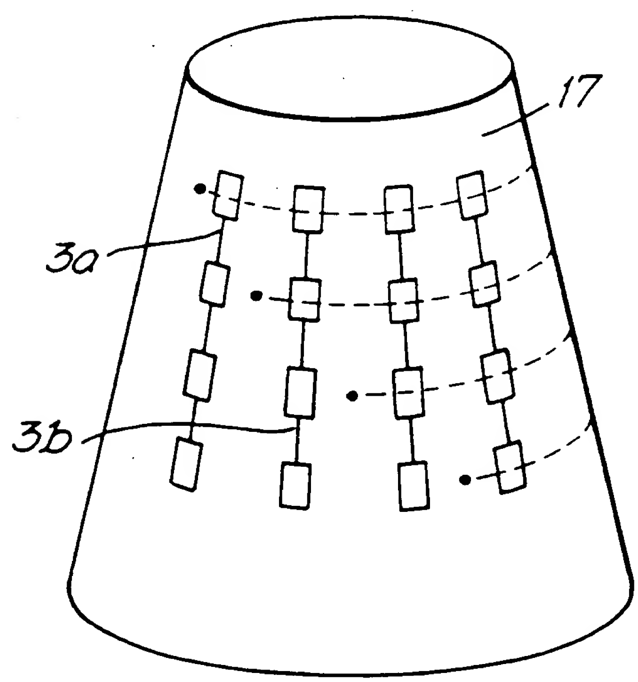


Fig. 5.



THREE-DIMENSIONAL PATCH ANTENNA ARRAY

This invention relates to microstrip patch antennas, which have particular applications in the fields of radar and communications.

In PCT patent application no W090/09042 there are described several embodiments of a planar rectangular array of microstrip patches comprised of a plurality of linear arrays of patches, the patches being coupled to a plurality of feed lines arranged transversely to the direction of the linear arrays, the effective separation of the patches along the feed lines being different for each feed line in order to generate a series of output beams overlapping in direction and hence producing the characteristic of a single broad beam but with a higher gain. The different effective separations of the patches along different feed lines in a rectangular array are achieved by means such as meanders in conducting strips or lengths of dielectric within waveguide feed lines.

The present invention applies the principle of changing the effective separation of patches along feed lines of a patch antenna array in a different way in order to provide an output beam extending radially outwards in a controlled direction from a defined axis.

This invention therefore consists of a patch antenna array disposed on a curved surface, the array comprising a series of planar linear arrays of interconnected patches coupled to feed lines disposed around the curvature of the surface and interconnecting the linear arrays in a direction transverse to the line of the arrays, the effective separation of the patches along each feed line and hence the input signal phase difference between adjacent patches being adjusted to correct for the curving of the array and thus generate a linear wave front giving a well-formed output beam.

The surface on which the array is disposed may, for example, be the curved surface of a cylinder or a truncated cone, in both of which cases the linear arrays would be disposed in generally axial directions and the feed lines in circumferential directions. The array may extend round the entire circumference of the surface, but since each feed line is required to form a beam in a given direction the feed lines do not extend round more than one half of the circumference, and in practice, the performance from a feed line is not significantly improved by extending it over more than one third of the circumference.

To provide a broad-beam or multi-directional output, adjacent feed lines are staggered relative to one another in a circumferential direction. The feed points of each feed line may be anywhere along their length. If the feed point is at the mid point of the feed line, then to generate an output beam normal to the line interconnecting the ends of the feed line the phase adjustments within the feed line are arranged to be symmetrical about the centre-point of the feed line.

If the feed point is at the end of a feed line, then symmetrical phase adjustments are no longer appropriate. The advantage of an end-fed line is that only one terminal impedance is required, but end-feeding is less appropriate, necessitating the provision of variable patch - feed line coupling, if a symmetrical amplitude taper across the array is required.

Two staggered feed lines of equal length will generate two beams separated by the degree of stagger. By providing a slightly asymmetric phase adjustment, an output beam correspondingly away from the said normal can be generated, and two or more beams can be generated from adjacent feed lines which diverge by more or less than the minimum stagger, if required. However, to minimise coupling between feed ports, the feed stagger should be arranged so that the beams are spaced by integral multiples of the orthogonal beam spacing.

By way of example, embodiments of the invention will now be described with reference to the drawing, of which

Figure 1 is a schematic, perspective view of an array antenna disposed on a cylindrical substrate;

Figure 2 is a schematic, part-elevation of the array of such an antenna illustrating the use of staggered feed lines to generate broad-band or multi-directional output beams;

Figure 3 is a schematic section along a centre-fed feed line illustrating the phase correction needed to generate a unidirectional output beam from the feed line;

Figure 4 is a detailed schematic part-elevation of three feed lines illustrating the variation of meander lengths in them which are required to achieve such a phase correction; and

Figure 5 is a schematic, perspective view of part of an array antenna disposed on the surface of a truncated cone.

With reference to Figure 1, an antenna array consists of a rectangular matrix of radiating patches 1 disposed on a cylindrical substrate 2 of a dielectric material and interconnected in an axial direction to form linear arrays 3a, 3b etc. The linear arrays are coupled together by circumferential feed lines 4a, 4b etc which are designed to give a beam essentially normal to a line connecting the ends of the feed line. The feed lines may be fed at their centre or either end, giving rise to a beam normal to the centre of the feed line. However, if the feed is designed to be fed from one end then feeding from the opposite end will generally result in a non-linear wave front and thus a poorly formed beam.

The actual form of construction of the patches and feed lines on the substrate may be conventional and may take one of the forms discussed in the specification of PCT patent application no WO90/09042. For example, whilst one surface of the substrate would normally incorporate a ground plane the feed lines could be suspended, for example by being formed as a etched pattern on the intermediate surface of a double layer of dielectric between the ground plane and the array lines formed, by etching for example, on the opposite face of the substrate.

Alternatively, the feed lines and array lines could be formed by a single matrix on the face of the substrate or be constituted by a waveguide or suspended stripline construction.

In practice it is most convenient for the input signal connection to the feed to be from within the cylindrical substrate, i.e. through, but electrically isolated from, the grounded inner surface of the substrate. The patches may be rectangular and configured to produce the desired polarisation effect, also as discussed in the earlier specification.

In the embodiment illustrated in Figure 2, a number of feed lines 4a, 4b, etc are disposed to couple with adjacent patches along the array lines 3a, 3b, etc and are staggered so that their feed locations 5a, 5b, etc at the end of each line are spaced apart from one another in a circumferential direction. If it is assumed that, as shown, the feed lines are of equal length and each extends over about one third of the circumference of the substrate then it can be seen that each line faces a slightly different general direction giving rise to the ability of the antenna to form a number of beams in different directions.

If the feed lines are straight between adjacent patches, then a difference in excited phase between adjacent patches results. The degree of phase difference depends on the radius of curvature of the substrate and the proportion of the circumference of the substrate covered by the feed line. This would result in a non-linear radiated phase front giving a non-optimum far-field beam. Although for some cases the degree of beam deterioration might be acceptable enabling a straight feed to be used, for most cases a uniform radiated phase front is desirable and the present invention is directed to this end.

This is achieved by generating a phase adjustment to the otherwise curved output wave front in order to generate a straight wave front, corresponding to a uni-directional beam, as shown in Figure 3. To produce a straight wave front (shown as the line 6 in Figure 3, which also shows schematically a number of patches 7 interconnected by a feed line 8 overlaying a curved substrate 9), a varying phase step in the feed lines between adjacent patches is required, and in this embodiment, and

shown in greater detail in Figure 4, this is achieved by placing meanders 10 of the appropriate length in the feed lines 11, 12 and 13 between patches 14.

The required lengths of the meanders are calculated on the premise that to generate a straight wave front the path lengths of signals from the central feed to the straight wave front via the first, second and every other patch must differ from one another by an integral number of wavelengths.

Thus, for a signal radiated from the nth patch outward from the central pair of patches of a centre fed line,

$$D_n + ns' + (m_1 + m_2 + \dots + m_n) = kL$$

where D_n is the free space distance of the nth patch from the central patches back from the wave front drawn through the central patches;

s' is the (constant) electrical distance (in the absence of meanders) between adjacent patches along the feed line;

m_n is the additional electrical length of the meander to be formed between the (n-1)th patch and the nth patch;

k is the lowest possible positive integer which gives a positive m_n; and

L is the free space wavelength of the beam.

Hence $$m_n = kL - D_n - ns' - (m_1 + m_2 + \dots + m_{n-1}) \qquad (1)$$

The value of m_n from Equation (1) is not a uniform step function of n, since the separation of patches along the feed line is typically of the order of 0·5L and the rate of increase of D_n increases with n.

Although the above formula has been illustrated using the symbols shown in the right-hand half of Figure 3, identical signals pass in both directions from the feed port 11 in the centre of the feed line. Since the arrangement is symmetrical, the formula, and corresponding meander lengths, are identical for each half of the line resulting in a configuration such as illustrated in Figure 4, which shows schematically

three staggered, centre-fed, identical feed lines 12, 13 and 14 incorporating meanders 10 between patches.

For each of the feed lines 12, 13 and 14 the signal from the feed point 15 passes along the feed line in both directions so that the meander lengths derived from Equation (1) apply symmetrically to both halves of the lines. Also, Formula (1) applies in an identical manner to each line so that the pattern of meanders is identical in each feed line, but displaced by the relative stagger of their feed points 15, this being in the case illustrated equal to the separation of adjacent array lines. The beams generated by the three lines will be directed normally to the respective lines at their mid point and will thus diverge from one another at an angle equal to the angular separation between adjacent array lines 16 at the axis of the cylindrical substrate. Since, from Equation (1), the electrical lengths of all the meanders are less than one wavelength, the meanders can be accommodated in the space available without difficulty.

Whilst Figures 3 and 4 and Equation (1) are based on a centre-fed feed line, the same considerations leading to a similar formula (but in general a rather different pattern of meander lengths) apply to feed lines fed at their end or at some intermediate point.

As mentioned above, the feed lines on a cylindrical substrate generate beams in directions normal to the axis of the cylinder. To meet a requirement for output beams in other directions, the array can be disposed on a substrate of truncated conical form, as illustrated in Figure 5. The operation of this embodiment is very similar to the cylindrical form, except that the output beams will be in a direction approximately normal to the array lines 3a, 3b, etc and thus (as seen in the figure) inclined upwards from the horizontal at an angle determined by the taper angle of the substrate 17.

To a first order, Formula (1) can be used to calculate meander lengths, but for different feed lines displaced along the conical surface the separation between array lines will be different so that a different value of s' applies.

CLAIMS

1. A patch antenna array disposed on a curved surface, the array comprising a series of planar linear arrays of interconnected patches coupled to feed lines disposed around the curvature of the surface and interconnecting the linear arrays in a direction transverse to the line of the arrays, the effective separation of the patches along each feed line and hence the input signal phase difference between adjacent patches being adjusted to correct for the curving of the array and thus generate a linear wave front giving a well-formed output beam.

2. A patch antenna array as claimed in Claim 1 in which the surface on which the array is disposed is the curved surface of a cylinder or a truncated cone, the linear arrays being disposed in generally axial directions and the feed lines in circumferential directions.

3. A patch antenna array as claimed in either preceding claim in which adjacent feed lines are staggered relative to one another in a circumferential direction.

4. A patch antenna array as claimed in any preceding claim in which the appropriate phase difference between adjacent patches is such that the path lengths of signals from an input signal feed point to a straight wave front differ by an integral number of wavelengths.

5. A patch antenna array as claimed in any preceding claim in which the effective separation of the patches along each feed line is determined by the length of meanders formed in the feed lines between adjacent patches.

6. A patch antenna array as claimed in Claim 5 in which input signals are fed to a feed point at the centre of each feed line and the additional electrical length of the meander formed between the (n-1)th patch and the nth patch from the feed point is given by

$$m_n = kL - D_n - ns' - (m_1 + m_2 + \dots + m_{n-1})$$

where the abbreviations are as hereinbefore defined.

7. A patch antenna array substantially as hereinbefore described with reference either to Figures 1 to 4 or to Figure 5 of the drawing.